The severe and disturbing decline of an iconic Mediterranean ecosystem endemic to Western Australia

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Introduction
Eucalyptus gomphocephala (Tuart) is an iconic woodland canopy tree, endemic to the Swan Coastal Plain of Western Australia, and one of few eucalypts able to dominate on calcareous soils. Unfortunately, less than one third of the original *E. gomphocephala* woodland ecosystem remains today (Government of Western Australia 2003), largely as a result of clearing for urbanisation, agriculture and industry. Equally disturbing is a decline of complex and unknown cause(s) within the Yalgorup region, south of Mandurah, 50 km south of the capital city of Perth. The decline and death of mature trees has been occurring within Yalgorup for approximately 15 years with the majority of the region affected and up to 100% mortality of *E. gomphocephala* in some locations.

Materials and Methods
A multi-faceted research program, largely focused on sites within the Yalgorup region over the last three years, has been attempting to find the cause(s) of this severe decline. A range of sites with varying depths to water table were established for water relations studies. Assessments of tree crown health, root health, mycorrhizal abundance and disease were also conducted at these sites with the aid of an Air Spade® to expose the root systems. Additional sites were established to look at the effect of fire on crown health of trees, restoration of *E. gomphocephala*, foliar nutritional status of *E. gomphocephala* and whether stem injection with a range of treatments (insecticide, nutrients, phosphite) could reverse crown decline. In the second phase of this research, twelve new sites have been established within the Yalgorup National Park using vegetation trend maps derived from Landsat Thematic Mapper satellite data. These sites are currently being used for analysis of high resolution multi-spectral airborne imagery, detailed crown assessments, foliar analysis, soil physical, chemical and biological analysis, assessment of microbial and mycorrhizal abundance and diversity, stem injections and the relationship between crown health and faunal diversity.

Results
The cause(s) of decline are still as yet unknown, however, preliminary findings suggest that the decline is complex and not due to a single cause. Vulnerability curves resulting from water relations measurements suggest that co-occurring species are not experiencing similar decline in crown health (*Eucalyptus marginata* and *Acacia cyclops*). *Eucalyptus marginata* trees have a similar cavitation response to *E. gomphocephala* with progressive exposure to tension in xylem, becoming fully embolised after pressure was induced to around 6 MPa. *Acacia cyclops*, on the other hand, became fully embolised at a much lower applied pressure, between 2 and 3 MPa.

Declining trees had lower numbers of fine roots and mycorrhizae associated with exposed root systems than healthy trees. Exposed fine roots from declining trees also showed characteristics of callus formation over the root tips, and proliferation of fine roots posterior to the callused tip. A new species of *Phytophthora* has been isolated from soils beneath declining trees where these symptoms have been observed. Pathogenicity trials are now in progress to determine whether it is able to cause death of fine roots as observed under declining trees in Yalgorup. Preliminary studies on the collection of mycorrhizal fungi revealed more fungi fruiting in healthy sites compared to declining sites.

Assessment of crown health of *E. gomphocephala* throughout Yalgorup National Park and the adjoining state forest, which are two areas with varying frequency of fire history, do not show a strong correlation between frequency of fire and crown health. However, preliminary work has indicated that in the year after a fire, crown vigour increased for trees lightly scorched by fire (<10% of the canopy) compared to trees in

an adjacent unburnt area. Findings have also confirmed the anecdotal reports that the survival and growth rate of *E. gomphocephala* is significantly greater on artificial ashbeds than off.

Comparison of the foliar nutrient concentrations observed in *E. gomphocephala* with those published for other eucalypts, shows levels of Zn and N that are particularly low in *E. gomphocephala* and these low levels tend to be more common in trees in the Yalgorup region, where canopy decline is severe. The application of a Zinc treatment or a Complete Nutrient treatment (containing N, P, K, Zn, Mn, Fe) stimulates canopy recovery, suggesting that Zn and other unidentified nutrients are limiting the growth of these trees. Trees injected with Fe alone and control trees slightly declined in health over a 12 month period while trees injected with Zn or a Complete Nutrient in combination with low rates of potassium phosphonate (25g/L & 50g/L) showed a good response. Recent soil analyses have shown a strong correlation between a particular functional group of bacteria and crown decline of *E. gomphocephala*.

Discussion

Many of the findings in this study are preliminary, but clearly show that there are numerous abiotic and biotic factors associated with the decline syndrome. This decline of the ecosystem is not only related to the crown health of mature *E. gomphocephala*, but also to the lack of recruitment of the species within the region. The crown decline of mature trees has resulted in an extreme lack of viable seed in the canopy, and as a result, efforts are underway to collect this valuable genetic resource. Furthermore, to assist in reversing the population decline, restoration trials investigating methods of increasing *E. gomphocephala* seedling survival and growth have been established at various locations in the Yalgorup region.

It is very difficult to determine in many cases whether the correlating factors described above are the cause or effect of the decline (e.g. foliar nutritional levels, soil microbial function). It is a strong possibility that many of them are inter-related. It could be proposed that the presence of a *Phytophthora* species, if pathogenic, may be causing the death of fine roots (Scott et al. 2007) which as a result, may cause an inability for the roots to connect with the beneficial mycorrhizal fungi resulting in a decline in the uptake of essential nutrients required for sustaining healthy crown vigour. The observation that trees respond to potassium phosphonate treatments lends support to a *Phytophthora* species potentially playing a role in the decline. *Phytophthora* species have been implicated in the decline of a number of tree species in Europe as a result of their impact on fine root health (Jonsson 2004, Jung et al. 2000, Jung et al. 1999). The pattern of spread of the decline of *E. gomphocephala* however is not typical of a disease solely caused by a root pathogen. It is therefore paramount that the various studies underway are conducted in an integrated way. The use of remote sensing technologies and GIS will enable a landscape approach to the research (Barber et al. 2007) and we hope, in association with the exhaustive ground-based studies, enable us to determine the cause(s) of this decline. Unless we can determine the cause(s) of this decline and find strategies to manage it, we may be faced with the imminent loss of a truly iconic, endemic woodland ecosystem.

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